EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 556
THEORETICAL, NUMERICAL, AND EXPERIMENTAL ANALYSES IN WOOD MECHANICS
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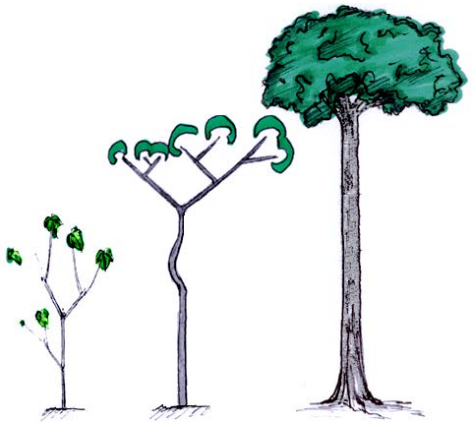
Effect of interlocked grain on wood mechanical behaviour in *Bagassa guianensis* in French Guiana

Julie BOSSU *PhD student – CNRS*

*UMR EcoFoG - **Eco**logie des **Fo**rêts de **G**uyane , French Guiana*



Bruno CLAIR**, CNRS, Kourou - **Supervisor

***Jacques BEAUCHENE**, CIRAD, Kourou*

***Mériem Fournier**, Agroparistech, Nancy*

Presentation outline

INTRO - French guiana timber context

- Ecological context
- Economical and social context

MATERIAL - Bagassa guianensis, promising species for local forestry

- Evaluate wood quality?
- Concept of paradoxical species
- Efficient wood characteristics

RESULTS – Interlocked grain, a singular structural characteristic

- Interlocked grain
- Pattern within the tree
- Mechanical properties depending of the scale of observation

Conclusion
Outlooks

Julie BOSSU - *PhD Student, CNRS*
EcoFog, French Guiana

Effect of interlocked grain on wood mechanical behaviour in *Bagassa guianensis* in French Guiana

INTRO - French Guiana timber context

1. **Ecological context**
2. **Local production**
3. **Economical and social context**

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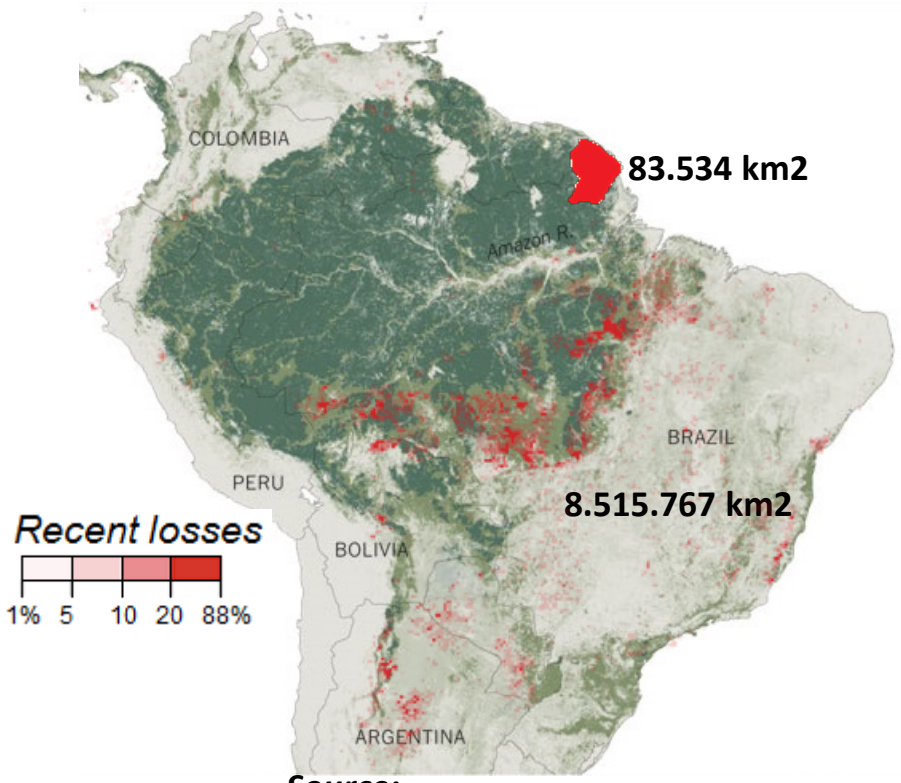
EcoFog, French Guiana

INTRO

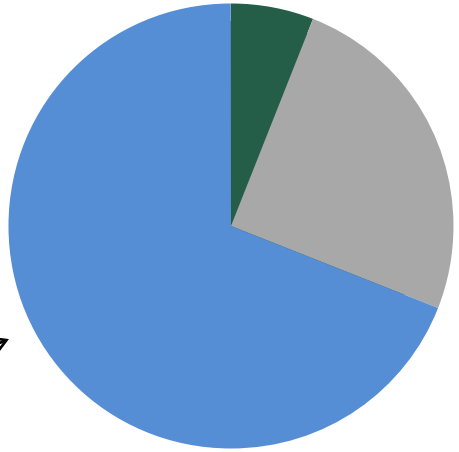
1. Ecological context

Favorable → Adapted region to try new sustainable models



Source:
Ruth S. DeFries et al., 2006

Forest cover :
8 Millions ha



Area monitored by the National Forestry Agency

Protected area of the Amazonian Park

- ✓ Well preserved region
- ✓ High biodiversity

INTRO

2. Local production

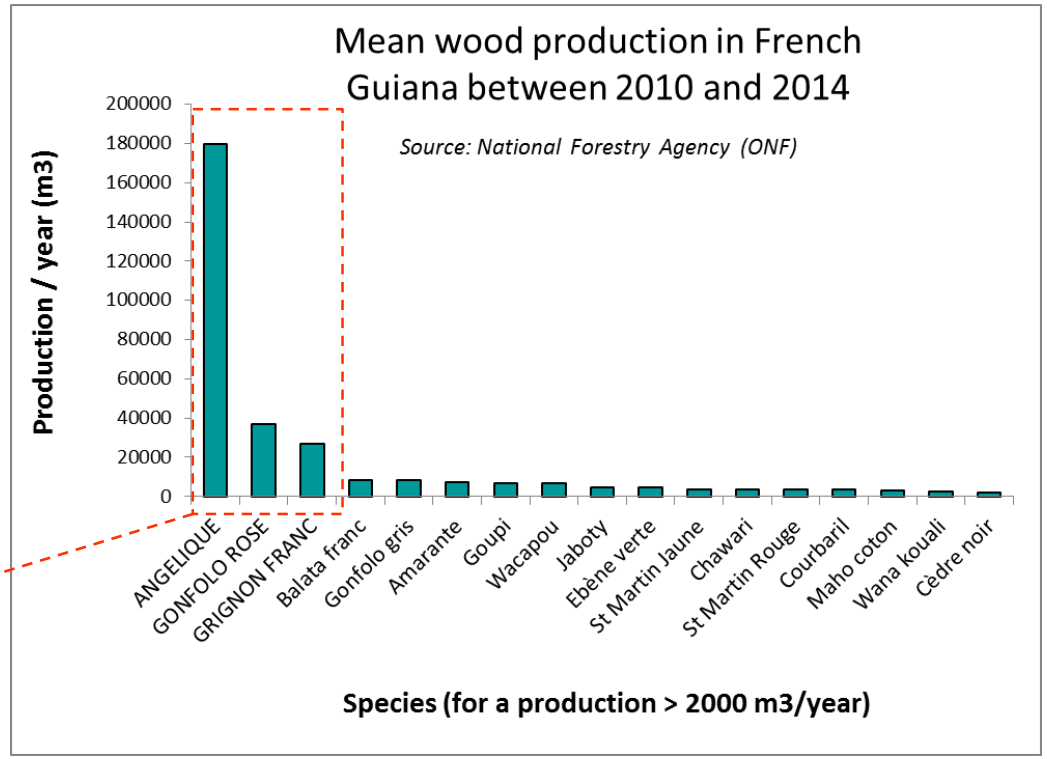
Small → Only adapted to a restrained market

1500 species identified
With **500** exploitable

Only **70** exploited

With only **3 species** representing 70% of the mean annual production:

- ***« Angélique » : Dypterix odorata***
- ***« Gonfolo rose » : Qualea rosea***
- ***« Grignon franc » : Sextonia rubra***



✓ Small and specific production
✓ System acceptable for a small demand

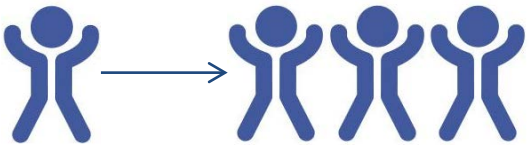
INTRO

3. Economical and social context

Requires rapid adaptations

High birth rates

Population x 3 within 50 years!



Very young population

One in two people is under 25 years

Current system of production need to be adapted!

Objectives :

1. **Provide the next generation**
2. **Avoid massive importation**

Plantations !

Effect of interlocked grain on wood mechanical behaviour in *Bagassa guianensis* in French Guiana

MATERIAL - Bagassa guianensis, promising species

1. How to evaluate **« wood quality »** among diversity?
2. Concept of **paradoxical species**
3. Species studied : ***Bagassa guianensis* (Aubl.)**
4. Properties leading to such **technological performances**
   - Specific gravity variations
   - Extractives reducing shrinkage

Julie BOSSU - *PhD Student, CNRS*
EcoFog, French Guiana

MATERIAL

1. How to evaluate « wood quality » among diversity?

What are we searching for?

➡

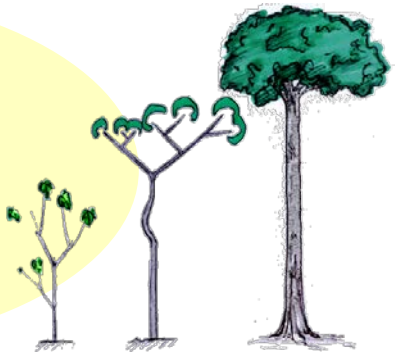
- ✓ **Fast-growing** species
- ✓ Adapted to **plantations**
- ✓ Quality wood for **timber**
- ✓ **Local** species

What kind of data set to represent wood quality?

Physical and mechanical database
(207 species)

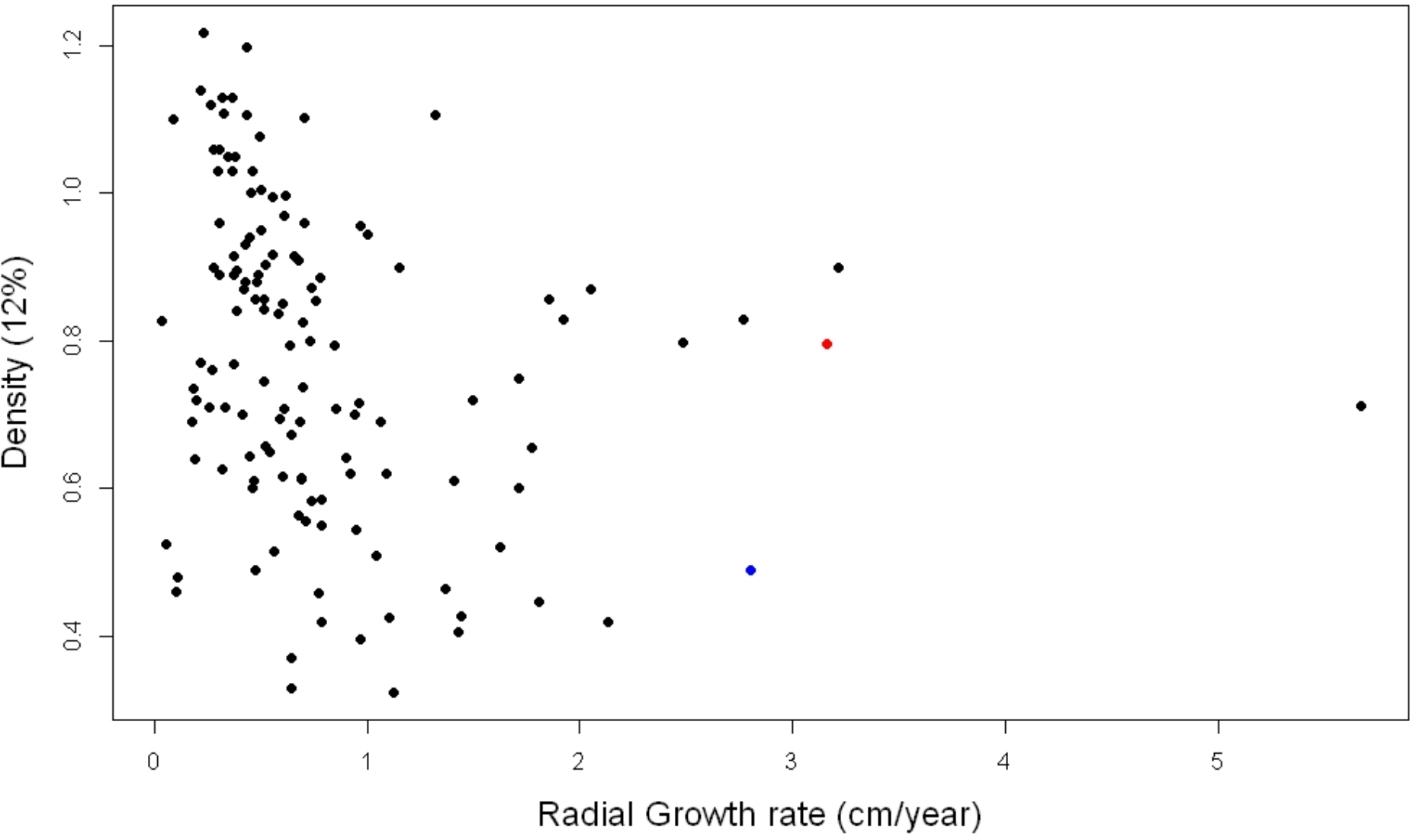
?

Growth monitoring database
(352 species)



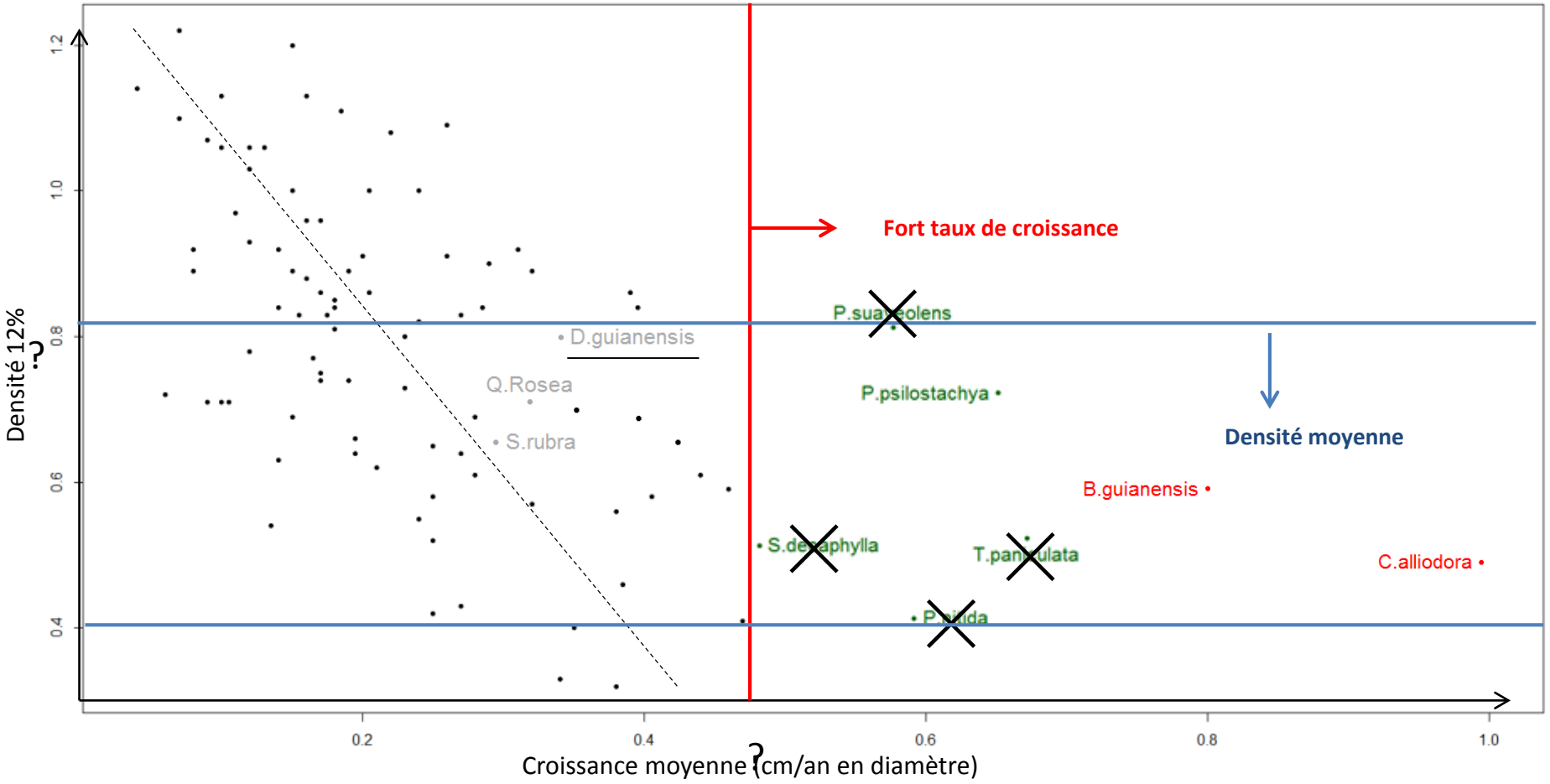
Crossing analysis

Promising species??


Density (12%)
0.4
0.6
0.8
1.0
1.2
0
1
2
3
4
5
Radial Growth rate (cm/year)

MATERIAL

2. Concept of paradoxical species



MATERIAL

3. Bagassa guianensis (Aubl.)

Family: Moraceae

15 years -> ∅ 25 cm

MATERIAL

4. Properties leading to such technological performances

- Specific gravity variations:

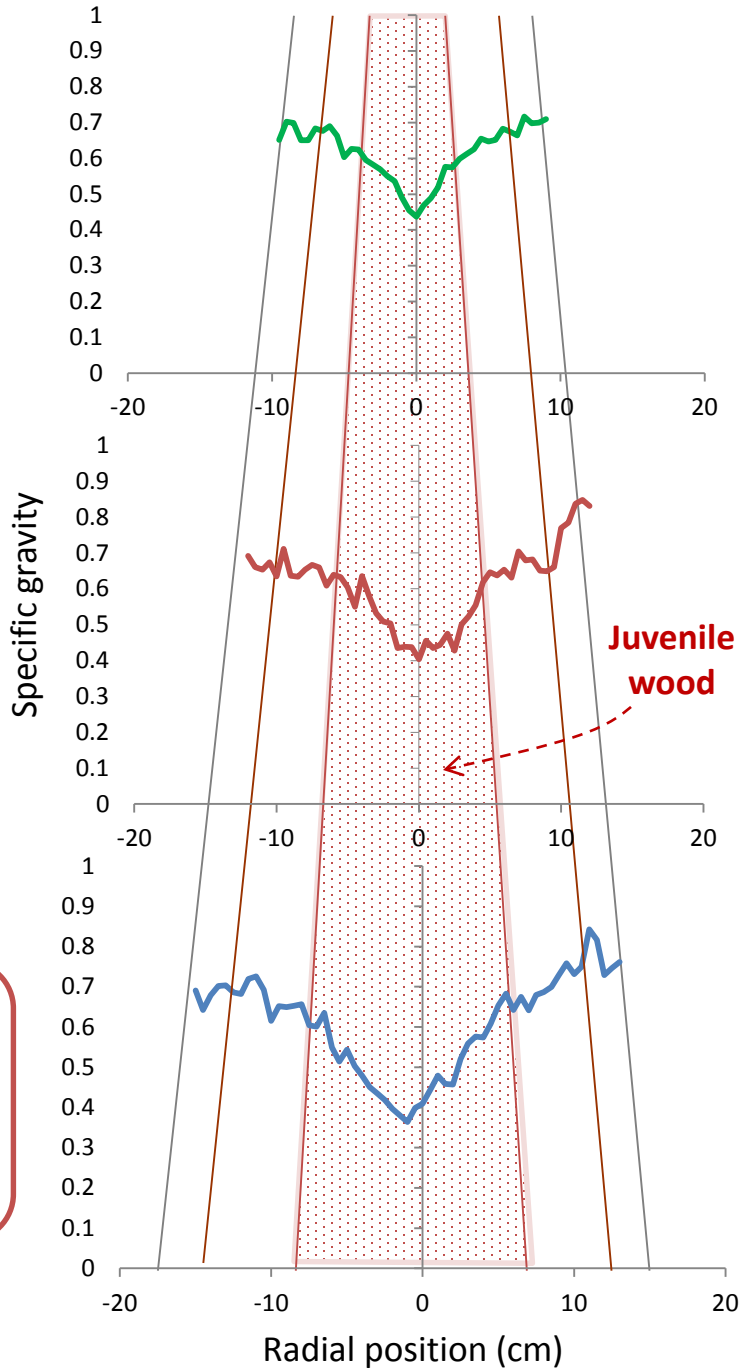
"Wood density is related to tree construction costs" (Larjavaara, 2010).

Heliophilous Pionners
- ✓ Grow fast
- ✓ Low density

Long lived Climax
- ✓ Grow slow
- ✓ High density

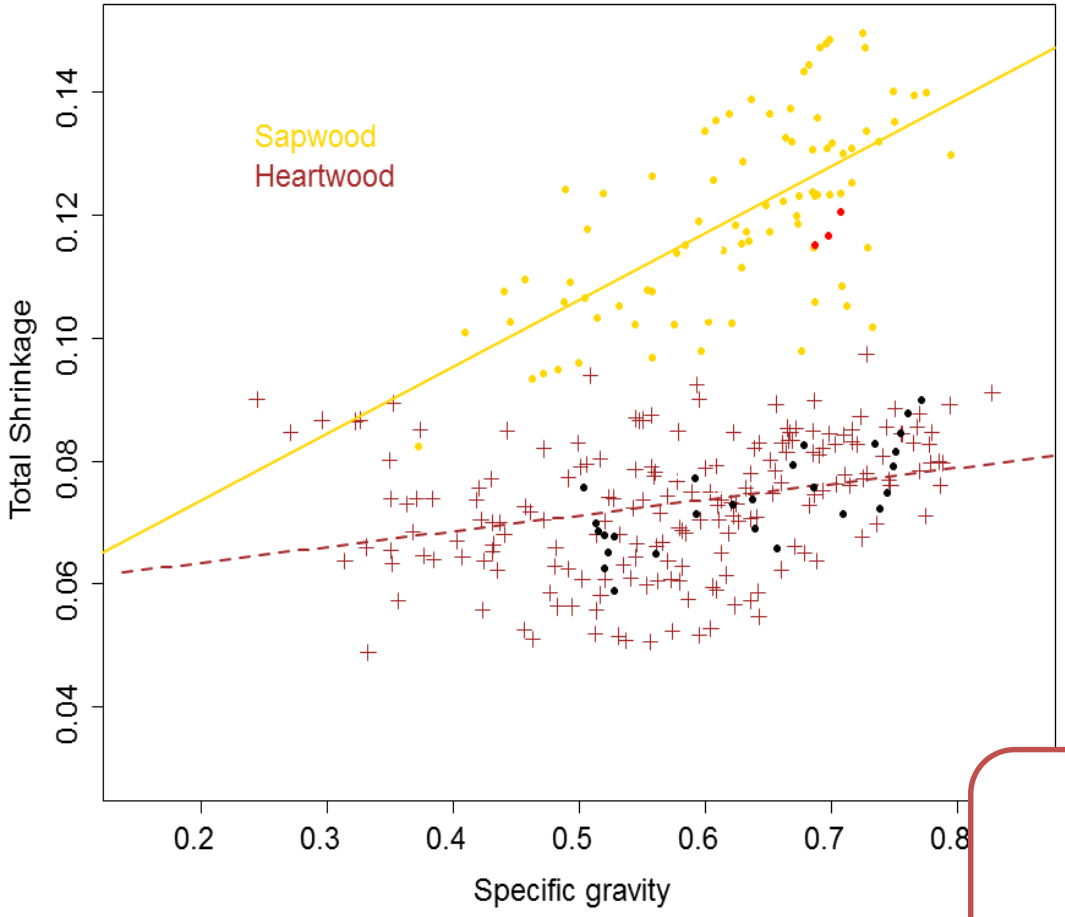
Mixed ecology: « Long Lived Pioneer »

>> High growth rate and perenity of the structure



MATERIAL

➢ Extractives reducing shrinkage :



- ✓ Extreme low shrinkage in heartwood (7.28%)
- ✓ Not linked with density as established
- ✓ After extraction: secondary metabolites from heartwood formation reduce shrinkage!

↓

Efficient extractives content

>> Exceptional low shrinkage and lower anisotropy

Effect of interlocked grain on wood mechanical behaviour in *Bagassa guianensis* in French Guiana

RESULTS – Interlocked grain, a singular structural characteristic

1. **What is interlocked grain?**
2. **Pattern within the tree**
3. **Fiber scale: link with MOE**
4. **Ring scale : tenacity**
5. **Trunk scale: flexibility**

Julie BOSSU - *PhD Student, CNRS*
EcoFog, French Guiana

RESULTS

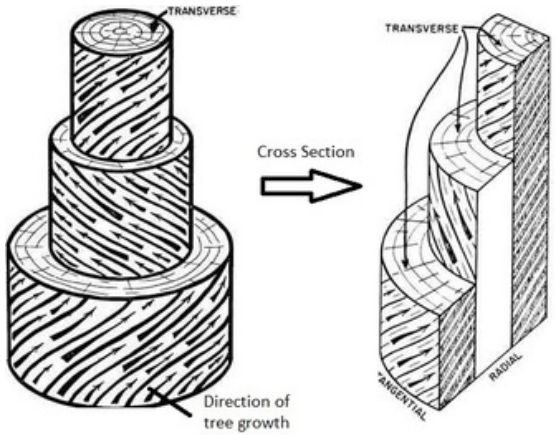
1. What is interlocked grain?

Result of wood anatomy:

During wood production -> formation of fusiform initials cells:

- ✓ Slightly inclined to the stem axis
- ✓ Inclination can change with time

-> Grain can be straight, wavy, spiral or **interlocked**



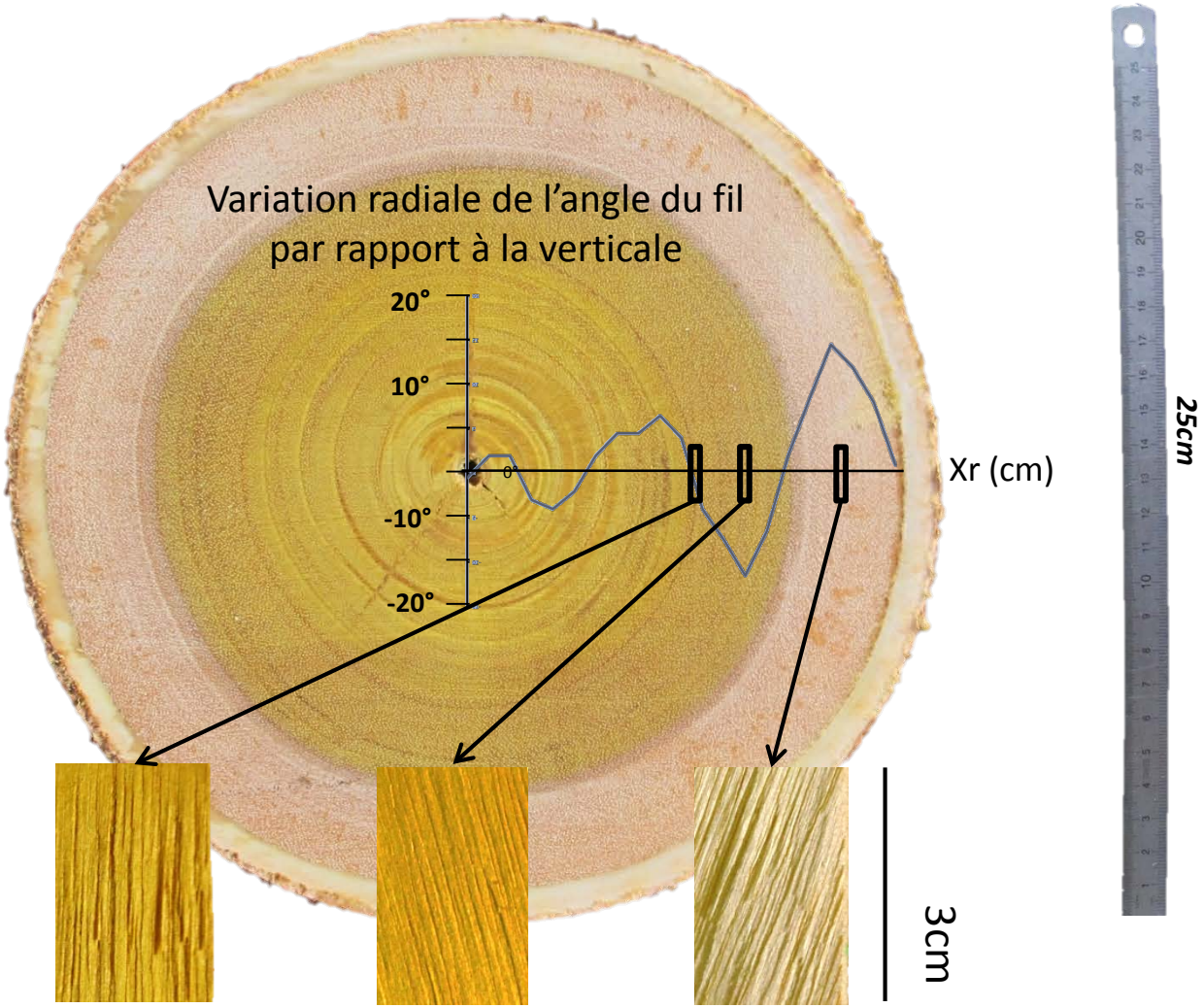
3 things we know:

- Inclination of fusiforms -> grain angle (Bath, 1983)
- Grain inclination cycles are temporal (Krawczyszyn, 1980)
- Interlocked grain -> MOE decreases (Cabrolier, 2007; Bremaud, 2012)

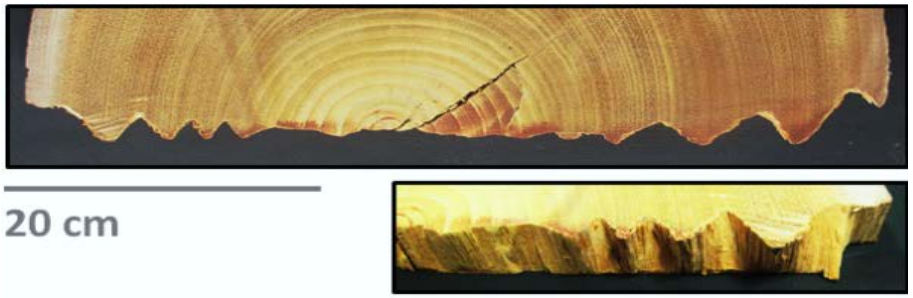
3 things we don't know:

- Signal responsible for inclination cycles ?
- Adaptative advantage for the tree ?
- Influence on tree mechanical behavior?

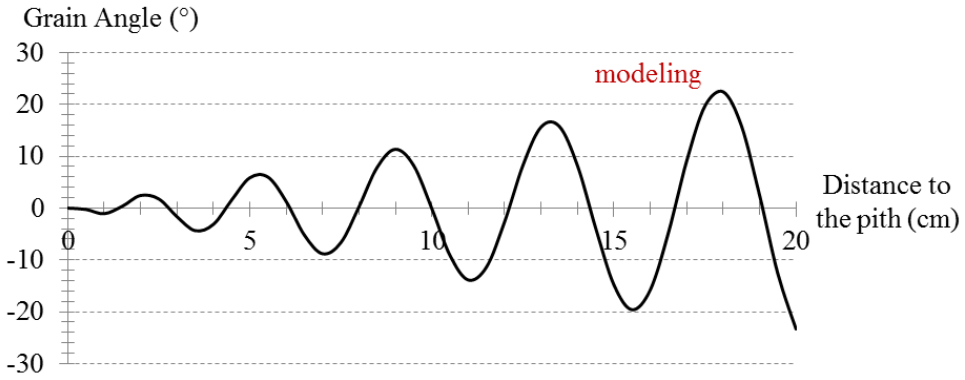
2. Pattern within the tree in B.guianensis



RESULTS



- For different radius : same number of grain periods
  -> confirmation of Krawczyszyn : **temporal pattern !**
- Yet « grain waves » amplitudes are **exceptional** (from -25 to 30° for mature specimens!)
- Really **homogeneous pattern** for all the individuals:



Consequence on wood material: Increase wood anisotropy in a longitudinal cut !

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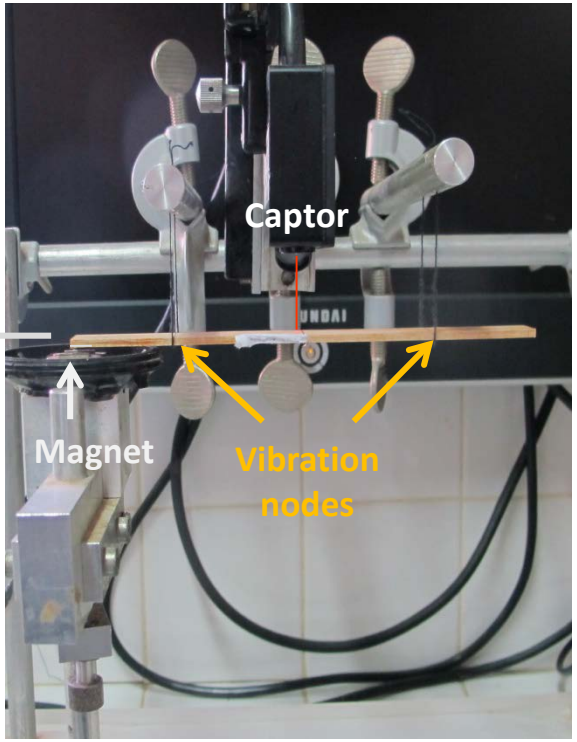
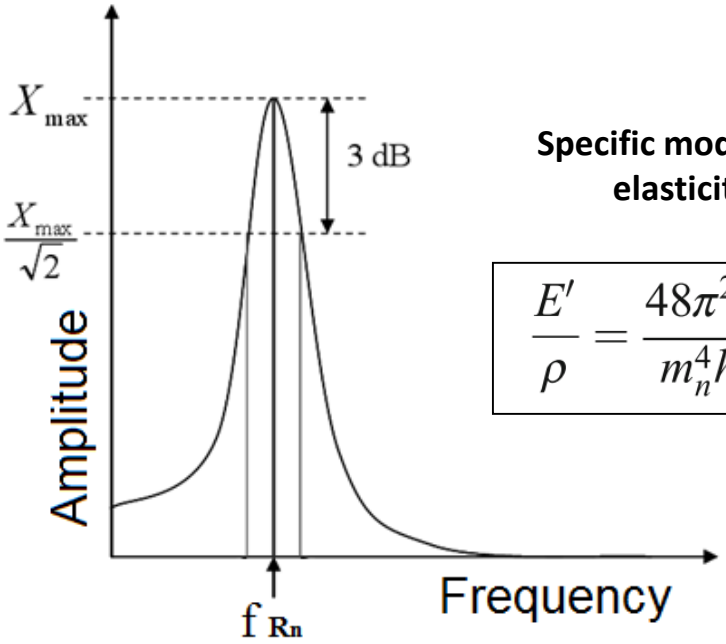
Might alterate wood mechanical behavior

3. Fibers scale (mm) : link with MOE





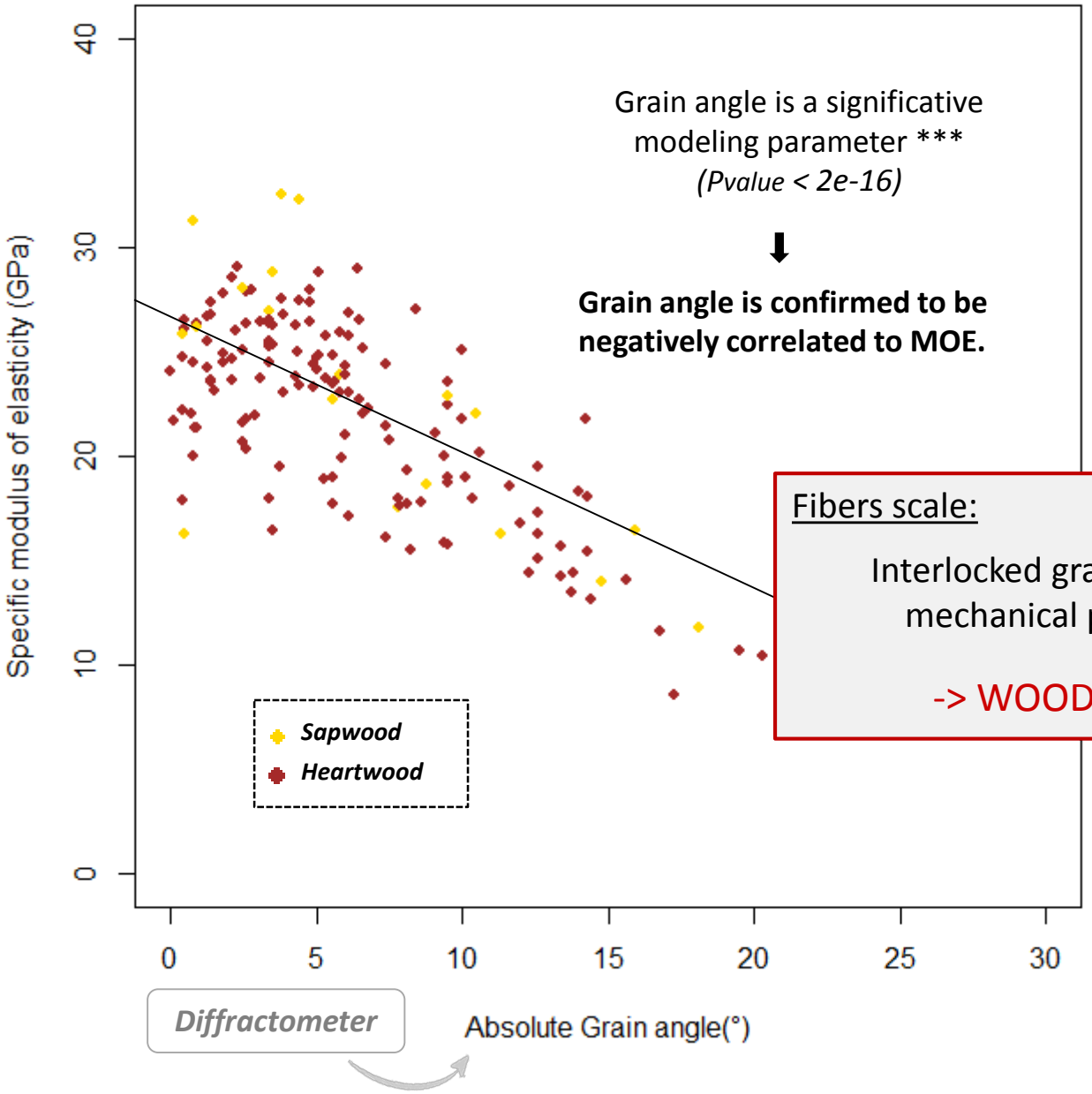
Specific modulus of elasticity:

$$\frac{E'}{\rho} = \frac{48\pi^2 l^4}{m_n^4 h^2} f_{Rn}^2$$

Where l = length; h = thickness; m_n = constant depending of the vibration node; f_{Rn} = resonance frequency.

RESULTS

Vibrations analysis



Diffractometer

Grain angle is a significative modeling parameter ***
(Pvalue < 2e-16)

⬇

Grain angle is confirmed to be negatively correlated to MOE.

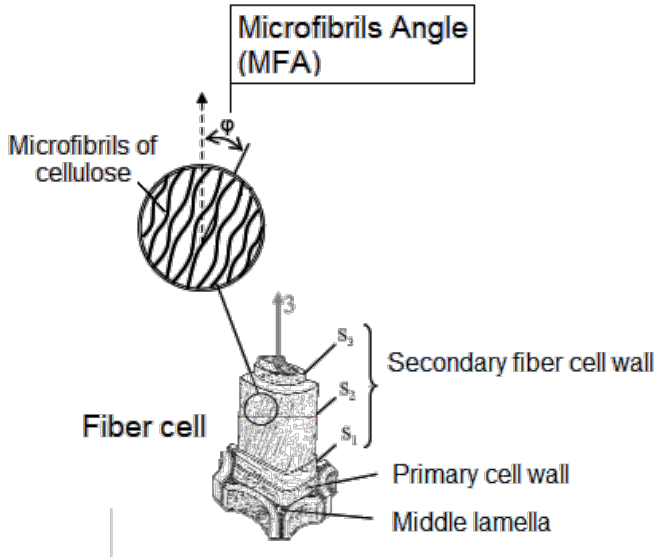
Fibers scale:

Interlocked grain cut down mechanical properties

-> WOOD FLAW!

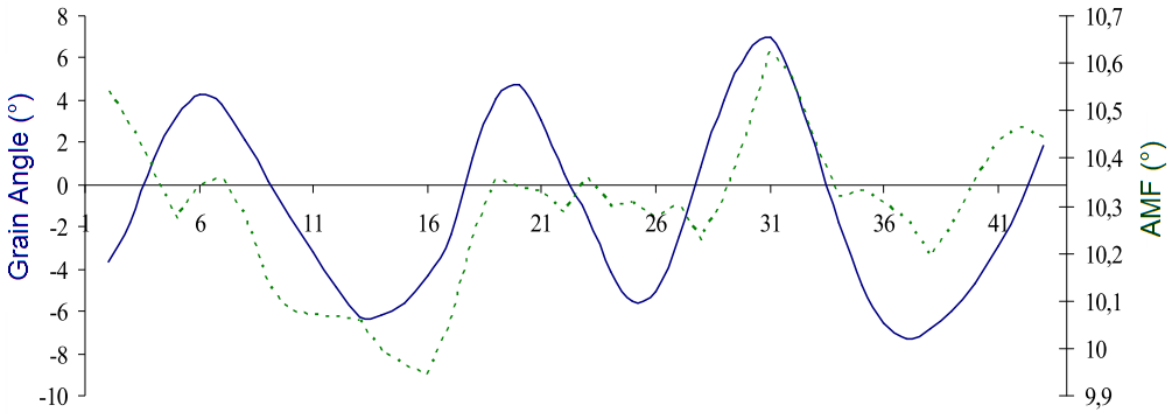
RESULTS

Microfibrils angle (MFA):



AMF variations might offset the effect of interlocked grain on MOE !

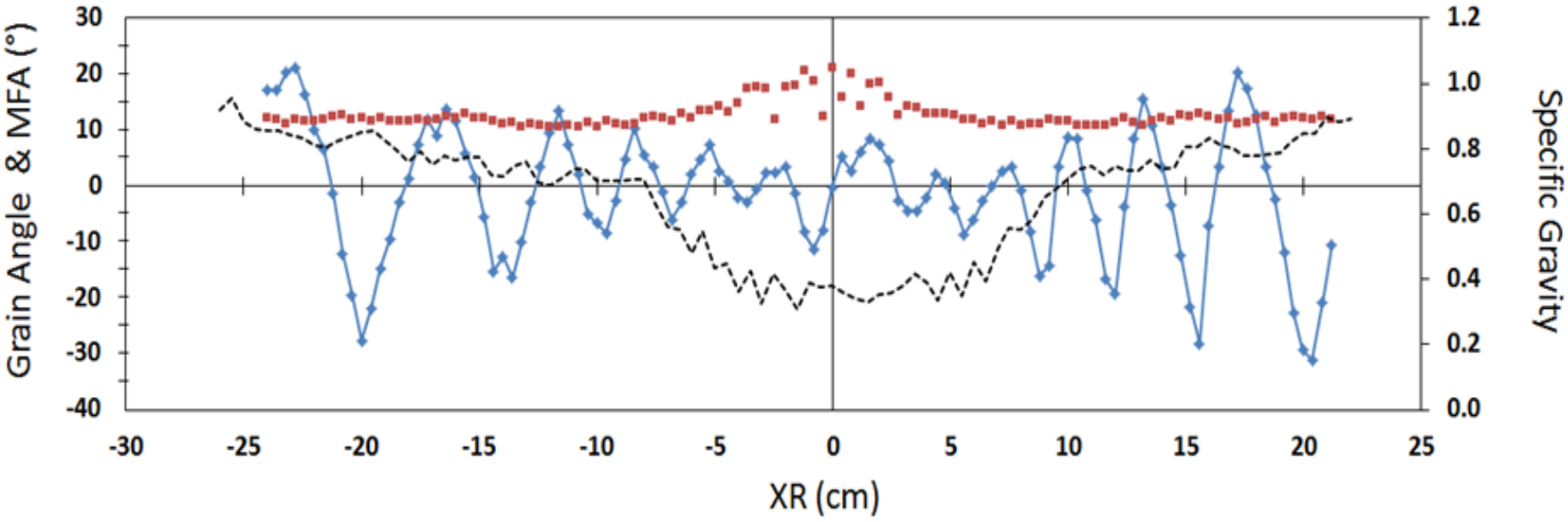
Example:
(Cabrolier, 2007)



RESULTS

Microfibrils angle (MFA):

Yet we measured slight variations in MFA:



⬇

MFA can’t offset interlocked grain effect on MOE!

RESULTS

4. Ring scale (cm) : tenacity test

Interlocked grain revent cracks propagation?

- ***R/T tenacity test:***

⬇

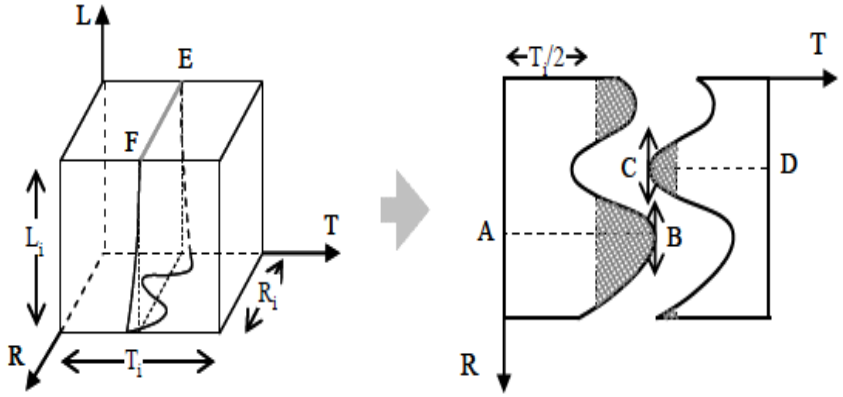
Strain/Stress graph

⬇

Gf = Maximum surfacic energy before fracture

σf = Maximal constraint before fracture

- ***Indicators of the grain angle deviation :***



⬇

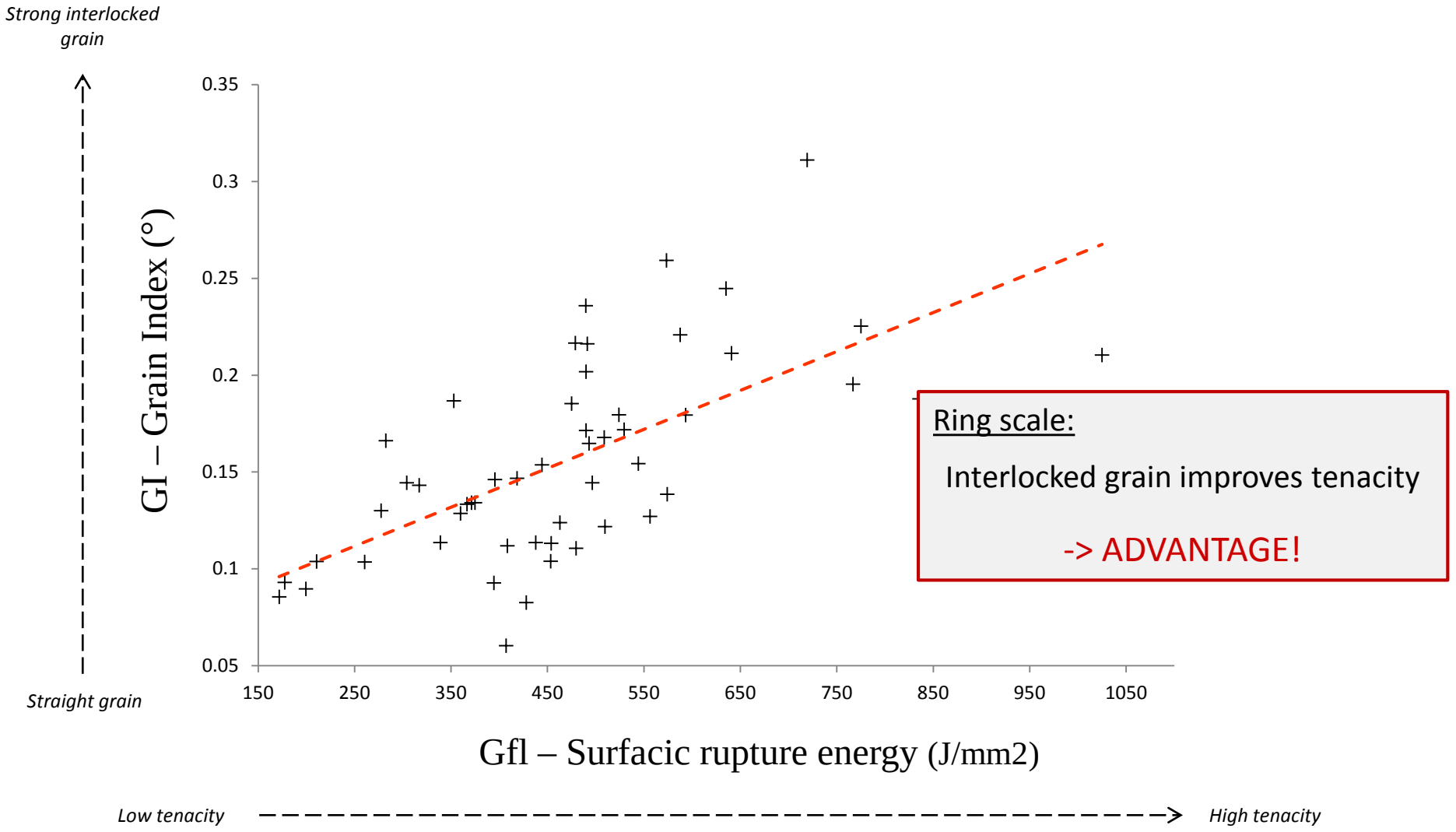
MDA : Maximum Deviation Angle

GI : Grain Angle

$$MDA = Atan\left(\frac{AB - \frac{Ti}{2}}{2}\right) + Atan\left(\frac{CD - \frac{Ti}{2}}{Li}\right)$$

$$GI = \frac{\text{Tinted Area}}{Ri}$$

RESULTS



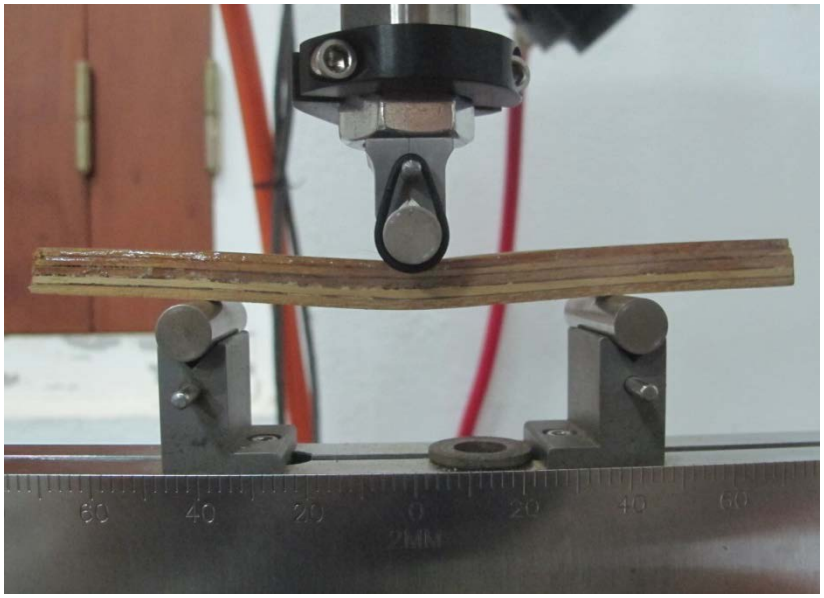
Ring scale:

Interlocked grain improves tenacity

-> ADVANTAGE!

5. Simulation of interlocked grain at trunk scale: flexion behavior

Interlocked grain improves flexibilty?

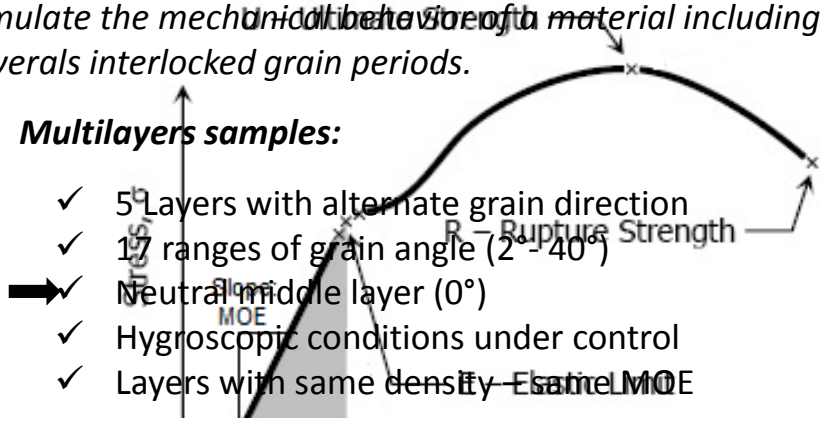


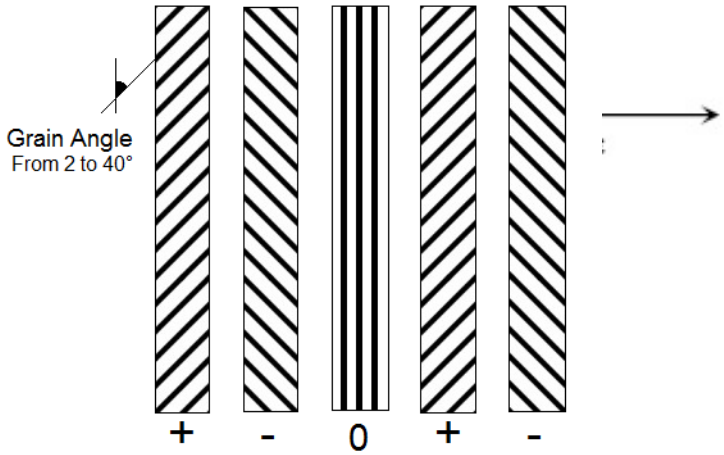
Artificial reconstitution of interlocked grain in the tree:

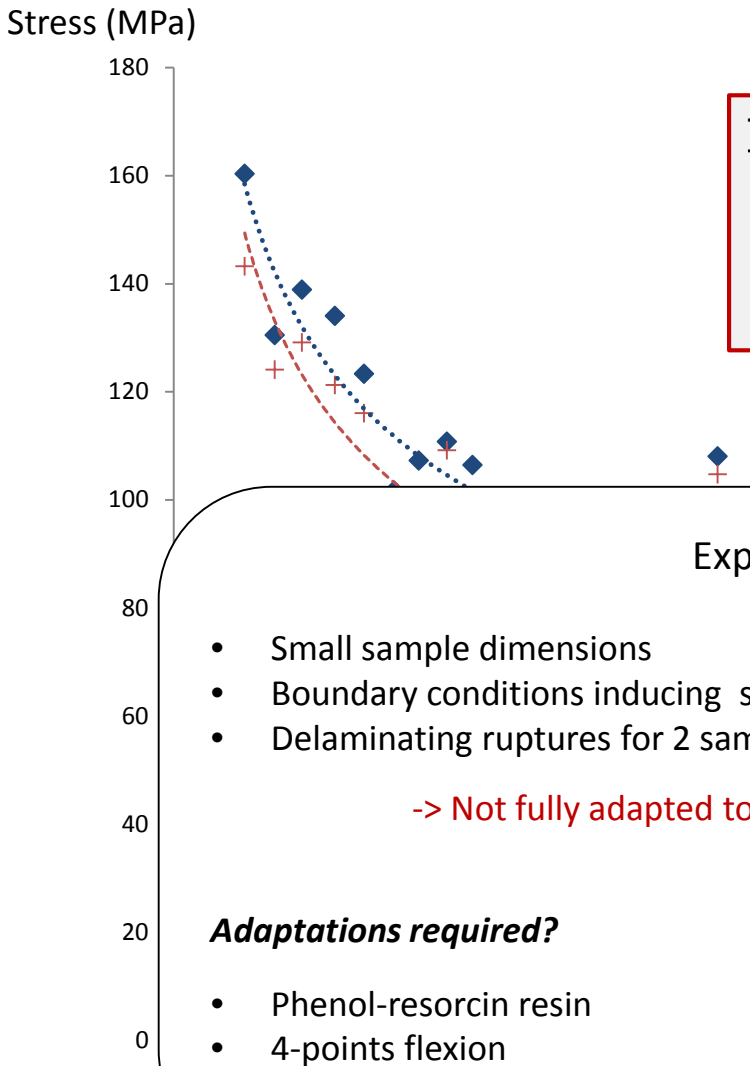
- ***Objective:***

Simulate the mechanical behavior of a material including severals interlocked grain periods.

- ***Multilayers samples:***
  - ✓ 5 Layers with alternate grain direction
  - ✓ 17 ranges of grain angle (2° - 40°)
  - ✓ Neutral middle layer (0°)
  - ✓ Hygroscopic conditions under control
  - ✓ Layers with same density – Same MOE







Trunk scale:

Interlocked grain reduces strength and yield point

-> DEFECT !

Caution!!

Experimental limits :

- Small sample dimensions
- Boundary conditions inducing shearing
- Delaminating ruptures for 2 samples with epoxy

-> Not fully adapted to simulate the real effect at trunk scale

Adaptations required?

- Phenol-resorcin resin
- 4-points flexion
- Compression tests

Conclusion

- **Paradoxical species combine high growth rate / medium density / low shrinkage**

  ⟹ ***Promising species for quality wood products***
  Well adapted for plantations

- **Example of an optimized tradeoff between strength and cost of construction**.

- **Interlocked grain:**

  - Strict pattern within the tree

    ⟹ ***Line guides for cutting process according to desirable uses***

  - Advantage or inconvenient depending on the scale length

    ⟹ ***Negative effect on MOE on microscale***
    But positive effect on tenacity on macroscale
    Need to be tested with larger samples to evaluate the effect on yield
    Effect on trunk torsion? Resistance to the wind?

  - Applications?

    ⟹ ***Necessarily advantageous for specific uses***
    Resistance to cracks -> can be used as cutting boards
    Construction : improve the strengtening of glued laminated timber

Julie BOSSU - *PhD Student, CNRS*
EcoFog, French Guiana

Outlooks

- **Next steps**
  - ✓ Valor
  - ✓ Impr
  - ✓ Pract

ties

- **Interlocke**
  - ✓ Link
  - ✓ Influe
  - ✓ Appli
    -
    -

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Julie BOSSU - *PhD Student, CNRS*
EcoFog, French Guiana

julie.bossu@ecofog.gf

Julie BOSSU *- PhD Student, CNRS*
EcoFog, French Guiana